

Claims

We claim:

- 1 1. A heat exchanger comprising:
 - 2 a. a manifold layer having a first plurality of openings for providing a cooling
3 material to the heat exchanger and a second plurality of openings for removing the
4 cooling material from the heat exchanger; and
 - 5 b. an interface layer coupled to the manifold layer, the interface layer having a
6 plurality of routes that each extends from one of the first plurality of openings and
7 terminates at a corresponding one of the second plurality of openings, the route for
8 carrying the cooling material, the plurality of routes each substantially contained
9 in a plane non-parallel to a heat-exchanging plane.
- 1 2. The heat exchanger of claim 1, wherein each route is adjacent to another route, whereby
2 heat can be exchanged between cooling material circulating within adjacent routes.
- 1 3. The heat exchanger of claim 2, wherein each route extends from one of the first plurality
2 of openings toward the heat-exchanging plane and then turns to extend away from the
3 heat-exchanging plane toward a corresponding one of the second plurality of openings.
- 1 4. The heat exchanger of claim 3, wherein each route is substantially U shaped.
- 1 5. The heat exchanger of claim 3, wherein after a route extends from one of the first
2 plurality of openings and before the route extends toward one of the second plurality of
3 openings, the route extends substantially parallel to the heat-exchanging plane.

- 1 6. The heat exchanger of claim 1, wherein the interface layer comprises a structural material
2 having a thermal conductivity of at least approximately 20 W/m-K.
- 1 7. The heat exchanger of claim 6, wherein the structural material comprises a
2 semiconductor.
- 1 8. The heat exchanger of claim 6, wherein the structural material comprises a metal.
- 1 9. The heat exchanger of claim 6, wherein the structural material comprises a porous
2 material that defines the plurality of routes.
- 1 10. The heat exchanger of claim 9, wherein the porous material comprises a porous metal.
- 1 11. The heat exchanger of claim 9, wherein the porous material comprises a silicon foam.
- 1 12. The heat exchanger of claim 6, wherein the structural material exhibits anisotropic
2 etching.
- 1 13. The heat exchanger of claim 12, wherein the structural material that exhibits anisotropic
2 etching is selected from the group consisting of micro-scale copper tubing and copper
3 filaments.
- 1 14. The heat exchanger of claim 6, wherein the structural material comprises a composite of
2 materials.
- 1 15. The heat exchanger of claim 1, wherein the cooling material comprises a liquid.

- 1 16. The heat exchanger of claim 15, wherein the liquid comprises water.
- 1 17. The heat exchanger of claim 1, wherein the cooling material comprises a vapor.
- 1 18. The heat exchanger of claim 1, wherein the cooling material comprises a gas.
- 1 19. The heat exchanger of claim 1, wherein the cooling material is air.
- 1 20. The heat exchanger of claim 1, wherein the first plurality of openings and the second
2 plurality of openings lie substantially in a single plane.
- 1 21. The heat exchanger of claim 1, further comprising a heat insulator between the first
2 plurality of openings and the second plurality of openings.
- 1 22. The heat exchanger of claim 21, wherein the heat insulator comprises an air gap.
- 1 23. The heat exchanger of claim 21, wherein the heat insulator comprises a vacuum gap.
- 1 24. The heat exchanger of claim 21, wherein the heat insulator comprises an insulating
2 material having a thermal conductivity of approximately 5 W/m-K or less.
- 1 25. The heat exchanger of claim 1, wherein a cross-sectional dimension of a route changes as
2 it extends from one of the first plurality of openings to one of a second plurality of
3 openings.

- 1 26. The heat exchanger of claim 25, wherein a cross-sectional dimension of a route increases
2 uniformly as it extends from one of the first plurality of openings to a corresponding one
3 of the second plurality of openings.
- 1 27. The heat exchanger of claim 1, further comprising a heat-generating device coupled to a
2 bottom surface of the interface layer.
- 1 28. The heat exchanger of claim 27, wherein the heat-generating device is formed integrally
2 with the bottom surface of the interface layer.
- 1 29. The heat exchanger of claim 27, wherein the heat-generating device is a semiconductor
2 device.
- 1 30. The heat exchanger of claim 1, wherein each route comprises a channel.
- 1 31. The heat exchanger of claim 1, wherein the plurality of routes is defined by a plurality of
2 pin fins.
- 1 32. The heat exchanger of claim 31, wherein the plurality of pin fins are positioned cross-
2 wise to the plurality of routes.
- 1 33. The heat exchanger of claim 1, further comprising a pump coupled to the first plurality of
2 openings.
- 1 34. The heat exchanger of claim 1, wherein the manifold layer and the interface layer form a
2 monolithic device.

- 1 35. A method of forming a heat exchanger comprising:
- 2 a. forming a manifold layer having a first plurality of openings for providing a
- 3 cooling material to the heat exchanger and a second plurality of openings for
- 4 removing the cooling material from the heat exchanger; and
- 5 b. forming an interface layer coupled to the manifold layer, the interface layer having
- 6 a plurality of routes that each extends from one of the first plurality of openings
- 7 and terminates at a corresponding one of the second plurality of openings, the
- 8 route for carrying the cooling material, the plurality of routes each substantially
- 9 contained in a plane non-parallel to a heat-exchanging plane.
- 1 36. The method of claim 35, wherein each route is adjacent to another route.
- 1 37. The method of claim 35, wherein each route extends from one of the first plurality of
- 2 openings toward the heat-exchanging plane and then turns to extend away from the heat-
- 3 exchanging plane toward a corresponding one of the second plurality of openings.
- 1 38. The method of claim 37, wherein each route is substantially U shaped.
- 1 39. The method of claim 37, wherein after a route extends from one of the first plurality of
- 2 openings and before the route extends toward one of the second plurality of openings, the
- 3 route extends substantially parallel to the heat-exchanging plane.
- 1 40. The method of claim 35, wherein the interface layer comprises a structural material
- 2 having a thermal conductivity of at least approximately 20 W/m-K.
- 1 41. The method of claim 40, wherein the structural material comprises a semiconductor.

- 1 42. The method of claim 40, wherein the structural material comprises a metal.
- 1 43. The method of claim 40, wherein the structural material comprises a porous material
2 defining the plurality of routes.
- 1 44. The method of claim 43, wherein the porous material comprises a porous metal.
- 1 45. The method of claim 43, wherein the porous material comprises a silicon foam.
- 1 46. The method of claim 40, wherein the structural material exhibits anisotropic etching.
- 1 47. The method of claim 46, wherein the structural material exhibiting anisotropic etching is
2 selected from the group consisting of micro-scale copper tubing and copper filaments.
- 1 48. The method of claim 40, wherein the structural material comprises a composite of
2 materials.
- 1 49. The method of claim 35, wherein the first plurality of openings and the second plurality
2 of openings lie substantially in a single plane.
- 1 50. The method of claim 35, further comprising forming a heat insulator between the first
2 plurality of openings and the second plurality of openings.
- 1 51. The method of claim 50, wherein the heat insulator comprises an air gap.
- 1 52. The method of claim 50, wherein the heat insulator comprises a vacuum gap.

- 1 53. The method of claim 50, wherein the heat insulator comprises a material having a thermal
2 conductivity of approximately 5 W/m-K or less.
- 1 54. The method of claim 35, wherein a cross-sectional dimension of a route changes as it
2 extends from one of the first plurality of openings to a corresponding one of the second
3 plurality of openings.
- 1 55. The method of claim 54, wherein a cross-sectional dimension of a route increases
2 uniformly as it extends from one of the first plurality of openings to a corresponding one
3 of a second plurality of openings.
- 1 56. The method of claim 35, further comprising coupling a heat-generating device to a
2 bottom surface of the interface layer.
- 1 57. The method of claim 56, wherein coupling a heat-generating device to a bottom surface
2 of the interface layer comprises integrally forming the heat-generating device to the
3 bottom surface of the interface layer.
- 1 58. The method of claim 57, wherein the heat-generating device is a semiconductor device.
- 1 59. The method of claim 35, wherein each route comprises a channel.
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- 1 60. The method of claim 35, wherein each route is defined by a plurality of pin fins.
- 1 61. The method of claim 60, wherein the plurality of pin fins are positioned crosswise to the
2 plurality of routes.

- 1 62. The method of claim 35, wherein the manifold layer and the interface layer form a
2 monolithic device.
- 1 63. The method of claim 35, wherein the step of forming an interface layer comprises
2 patterning a semiconductor device and etching the patterned semiconductor device to
3 form the interface layer.
- 1 64. The method of claim 35, wherein the step of forming an interface layer comprises
2 stamping a sheet of metal in the shape of the plurality of routes.
- 1 65. The method of claim 35, wherein the step of forming an interface layer comprises
2 injection molding a metal in the shape of the plurality of routes.
- 1 66. A method of cooling a device comprising transmitting a cooling material from an inlet
2 manifold, through a plurality of stacked routes positioned over the device, and to an outlet
3 manifold.
- 1 67. The method of claim 66, wherein the stacked routes comprise a structural material having
2 a thermal conductivity of at least approximately 20 W/m-K.
- 1 68. The method of claim 67, wherein the structural material comprises a semiconductor.
- 1 69. The method of claim 67, wherein the structural material comprises a metal.
- 1 70. The method of claim 67, wherein the structural material comprises a porous material that
2 defines the plurality of stacked routes.

- 1 71. The method of claim 70, wherein the porous material comprises a porous metal.
- 1 72. The method of claim 70, wherein the porous material comprises a silicon foam.
- 1 73. The method of claim 67, wherein the structural material exhibits anisotropic etching.
- 1 74. The method of claim 73, wherein the structural material exhibiting anisotropic etching
2 comprises a material selected from the group consisting of micro-scale copper tubing and
3 copper filaments.
- 1 75. The method of claim 67, wherein the structural material comprises a composite of
2 materials.
- 1 76. The method of claim 66, wherein the plurality of stacked routes comprises pin fins.
- 1 77. The method of claim 66, wherein the cooling material comprises a liquid.
- 1 78. The method of claim 77, wherein the liquid is water.
- 1 79. The method of claim 66, wherein the cooling material comprises a vapor.
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- 1 80. The method of claim 66, wherein the cooling material comprises a gas.
- 1 81. The method of claim 66, wherein the cooling material is air.